THE HISTORY AND DEVELOPMENT OF THE BUREAU OF STANDARDS RADIO BEACON EXPERIMENT STATION AT COLLEGE PARK, MD.

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SUMMARY

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INTRODUCTION

The widespread use of heavier-than-air craft today renders difficult the realization that mankind's first successful powered flight in an airplane was made by Wilbur Wright just 33 short years ago. The intervening years have witnessed such improvements in safety, comfort, speed, and flexibility, that in 1936 the airline is an accepted channel of passenger and light-freight transportation, rendering rapid and convenient service on a definite time schedule. This phrase "on a time schedule" is especially significant, since only by the maintenance of a dependable schedule can the airlines attract the patronage of individuals and concerns with whom time is a major consideration.

As long as the pilot was frequently doubtful of his ability to ascertain his position with respect to points on the earth, a time schedule was impossible. Hence, the history of commercial aviation is, to a large extent, the history of efforts made to overcome the limitations on visibility imposed by weather conditions.

Quite early in the game it became apparent that any practical solution of the problem of blind flight must come through the use, in some form, of the principles of radio. The altimeter, compass, and other standard airplane instruments make the task of actually maintaining flight while fog-bound a comparatively simple one. In fact it is quite easy by proper use of the compass to preserve any <u>direction</u> of flight desired. However, the effect of wind-drift, the extent of which must remain unknown to the pilot, renders almost impossible the task of arriving at any given <u>point</u>.

With no visible landmark against which to check, the increase or diminution of speed, or the side-drift with respect to the ground is not determinable. The result might conceivably be the exhaustion of fuel in an out-of-way or unlandable area. In any event inconvenience and delay are met.

The use of the radio links the plane to the invisible earth so that not only the proper direction, but also the proper route in that direction are maintained. This paper will aim to point out the major developments in the evolution of airway radiobeacons for this purpose.

Most of the important work on radiobeacons in this country was carried on by the U. S. Bureau of Standards, in large part at the airport in College Park. The history of the experiment station set up at this airport for use in the development is, in itself, of small interest. Indeed, a chronology of this station is not available. However, a description of the work done at College Park and the unfoldment of the system worked out are tantamount to a history of the station. Hence, this paper must deal largely with the airway radiobeacon as such.

The experiments at College Park consisted of two phases of approximately equal importance. These are the development of the airway radiobeacon proper, and that of radio blind-landing aids. The work was done on these two problems concurrently, but only the phase of the airway radiobeacon has been treated herein, leaving the discussion of the blind-landing material to some future initiate. Any difficulty experienced in the writing of this thesis has arisen entirely from the wealth of data available which had to be sifted and shortened in order that the paper would not be too voluminous.

It is with the thought in mind of presenting only the most pertinent facts that this thesis has been written.

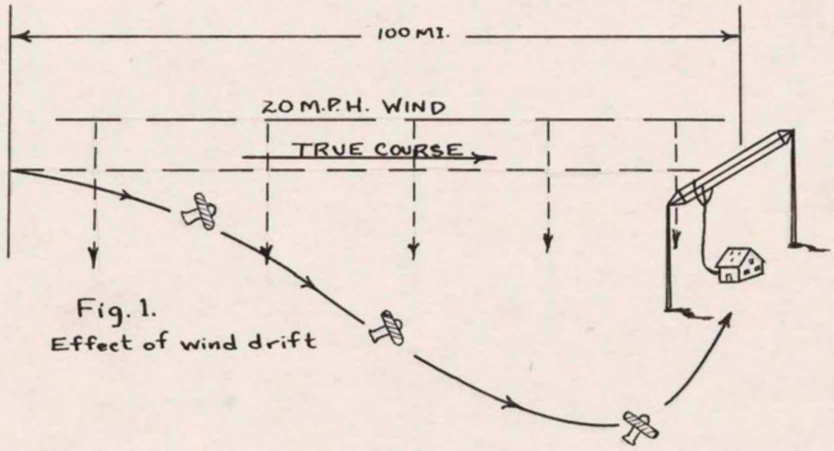


Fig. 1.
Effect of wind drift

EARLY DEVELOPMENT

The needs of military flyers during the World War were the incentive for the first work done in adapting the radio to airplane guidance requirements. The inherent need of fighting aircraft is for an extremely flexible system of guidance. There can be in this type of work no fixed airways such as are needed by commercial lines. Because of the well known directional properties of the loop antenna, this was the equipment used in the early work in the field. The reception characteristic of the loop antenna is in the form of a figure eight, with the long axis in the plane of the loop. Hence, when the loop is rotated, the strongest signals are received when its plane passes through the source of the signal. In this system a receiving set carried by the plane picked up the signals transmitted from a ground station on the loop antenna of the receiving set, and thus gave the proper direction of the source, which was located at the home field. If there were side winds the effect would simply be to shift the plane from its course and change the direction of the station in relation to the plane. By continually flying in the direction of the received signals the pilot would eventually arrive at the landing base, although he might reach it in a very round-about manner (see Fig. 1). A great deal of trouble was experienced with the receiving apparatus on the planes, and the system was found to be generally inadequate.

Another system which patterns closely after the one just described was brought forth as a next logical step. It is, incidentally, the one in wide use in Europe, though outmoded in this

country. Each airplane carries a trailing wire antenna, which has no directional properties. Ground stations, on radio request from the airplane determine its direction from their loop antennae, and several radio their findings to the plane, which may then ascertain its position by triangulation. This requires two-way equipment both on the ground and in the plane. Moreover, if a large volume of flying is being done, the system is inadequate to take care of more than one plane at a time. In bad flying weather, when most needed, the system thus becomes jammed.

THE AURAL RADIOBEACON

The next important development was undertaken in 1920 by the Bureau of Standards at the request of the Army Air Service. Cooperating in this work were the Bureau of Lighthouses, and the Army Signal Corps and Air Service. It is on the work begun at this time that the entire subsequent experiments were based. Hence, a thorough understanding of the principle involved is necessary for an appreciation of the work done at College Park.

Use is again made of the characteristics of the loop antenna. It has been previously noted that the receiving characteristic is in the shape of a figure eight. The transmitting properties are similar, the signals being strongest in the direction of the plane of the coil, and no signals at all being received on a line through the middle of the eight in a direction of 90 degrees to the plane of the coil. Thus, in Fig. 2 , the strongest signal is received on line OD', proportional to OD; no signal on line OO'; and the signals received on OA', OB', OC', are proportional to OA, OB, OC, respectively.

If two such coils are used at an angle to each other, the resulting combined transmission characteristic will be as shown in Fig. 3 . It can easily be seen that the signals will be of equal intensity on the bisectors of the angles between the coils, and in no other directions. It may also be seen that the signals become of unequal intensity very rapidly as the receiver moves off of this line. Thus, in effect, there are set up 4 narrow sectors of equal signals from each coil. If power is put on the coils alternately, a signal is received in such a sector from one antenna, and a moment

later a signal of equal intensity from the other. Thus a plane being guided by such a device would travel to or from the transmitter on an equal signal sector. The moment the plane was blown off the course by a side wind the pilot would know, because of the resulting variation in intensity of the two signals.

As developed by the Bureau of Standards originally, the Morse letters "A" and "T" were sent out, one on each antenna. A 2 kilowatt quenched spark transmitter was used with a double-pole double-throw switch to change the radio-frequency power from one antenna to the other. The frequency used was 300 kilocycles. Reception was by headphones, thus giving rise to the name "aural radiobeacon". In tests conducted at that time it was found that the equisignal zone was approximately 1.5 miles wide at a distance from the source of 31 miles. This was due to the difficulty in detecting small changes of signal intensity by ear. The angle between the two antennae was 143.5 degrees. These initial tests were made on signals generated at the Bureau of Standards as received on board the Bureau of Lighthouses vessel "Maple" in the Potomac River just off Mathias Point. Many interesting effects were noted in these tests, but unfortunately a detailed description of them is beyond the scope of this paper. One, however, is important enough to merit attention. It was found that unequal current distribution in the coil impaired its directive properties. (See Fig.4 and Fig.5).

The Bureau had now demonstrated conclusively that the theory underlying the new invention was borne out in practice. However, there had as yet been no actual flying tests, because a

boat had been used in these experiments. Since the work was being done in close cooperation with the Army, an Army field was chosen for adaptation of the method to aircraft. McCook Field at Dayton, Ohio, was selected for this purpose by the Army engineers.

The refinements upon the original apparatus were numerous in this new location. The antenna changeover was accomplished automatically and the coils were placed at a 135 degree angle. A 5 kilowatt set was used, transmitting on 300 kilocycles, but the connections were essentially as originally set up at the Bureau of Standards. It was brought out that the equisignal zone of the crossed loops was shifted by unequal current values in the loops. Moreover it was noted that in flight the zone was shifted by the directional receptive qualities of the trailing wire antenna used. A heavy and short trailing wire, hanging nearly vertical from the plane, was found to correct this effect.

At this juncture the Bureau of Standards, having fulfilled the request of the Air Service, dropped from the picture; and the following four years witnessed development of the radiobeacon by the Army engineers alone.

Of incidental interest is the fact that at about this time the term "radio range" came into use to mean any directive radiobeacon transmitting apparatus.

The chief contributions of the Army engineers during this 4 year period were in the development of a signal interlocking device and a goniometer for rotating the equisignal zones through space without moving the antenna loops. Both of these steps were based on patents issued in 1907; the first to a German,

O. Scheller; the other on the Bellini-Tosi system. The Army men simply combined the two foreign patents into a system useable in radio range operation. The exact nature of these improvements will be explained in the article on the subsequent work done at College Park.

Early in 1926 there was before Congress a bill to create an Aeronautics Branch of the Department of Commerce to supervise commercial aviation. The proponents of the measure in the Department of Commerce requested that the Bureau of Standards submit to them ways in which radio might be used in airway navigation aids by the proposed Branch. When the bill passed, the Bureau was called upon to do research work along the lines which it had suggested while the law was pending.

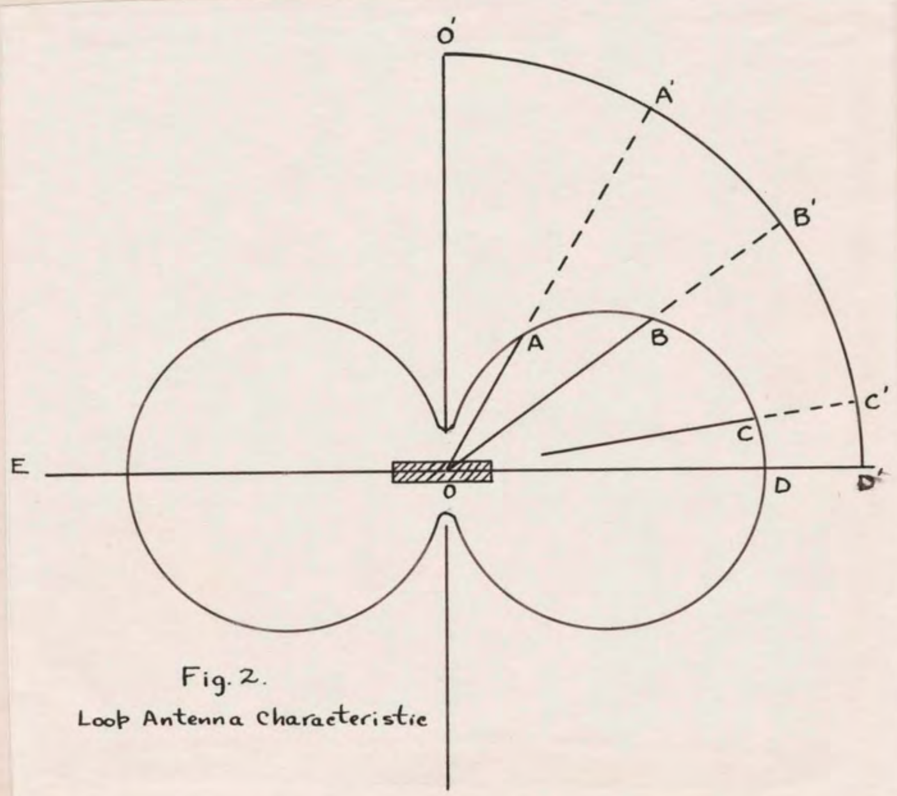


Fig. 2.
Loop Antenna Characteristic

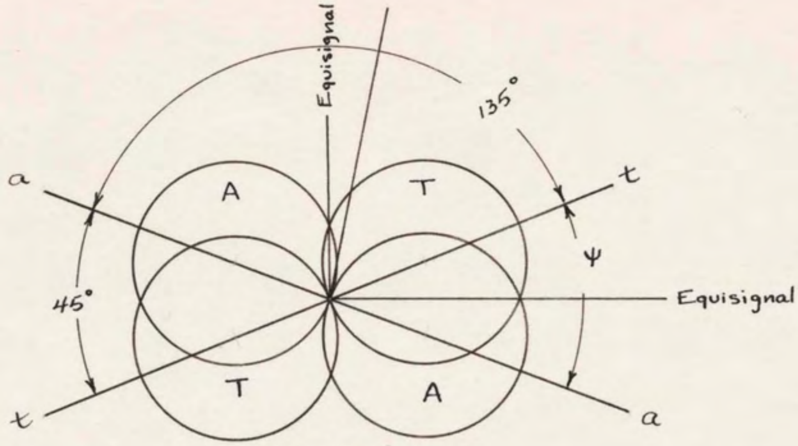


Fig. 3.
Combined Characteristic of 2 loops

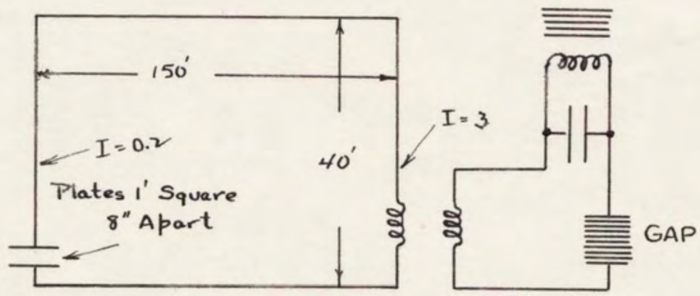


Fig. 4.
Unequal Current distribution
in loop

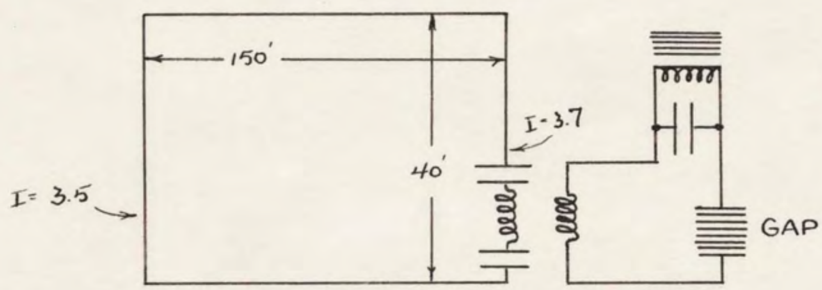


Fig. 5
Equal current distribution
in loop

THE COLLEGE PARK STATION

A site near the Bureau of Standards was needed for the research work now necessary. The airport at College Park was chosen because it is a large, flat field, sufficiently close to the Bureau, and free from any wires which might interfere with the experiments. The station consisted of a small frame structure with a tower mounted on top of it on which to place the antennae. It was equipped with radiobeacon, radiotelephone, and radiotelegraph apparatus. A picture of the station and antennae used may be seen in Figure 6. This station was begun in July of 1926, immediately that the Bureau received its assignment.

At the same time a similar station was set up in the dangerous mountain area at Bellefonte, Pa. on the New York-Cleveland airway. This station was transferred to the Airways Division of the Commerce Department in 1928 to give radio service to the airway on which it is placed.

To begin with, it was desired (1) to improve the design of the existing apparatus; (2) to replace the aural reception of the signals with visual reception; and (3) to develop the equipment so that several intersecting courses could be laid out from the same piece of apparatus.

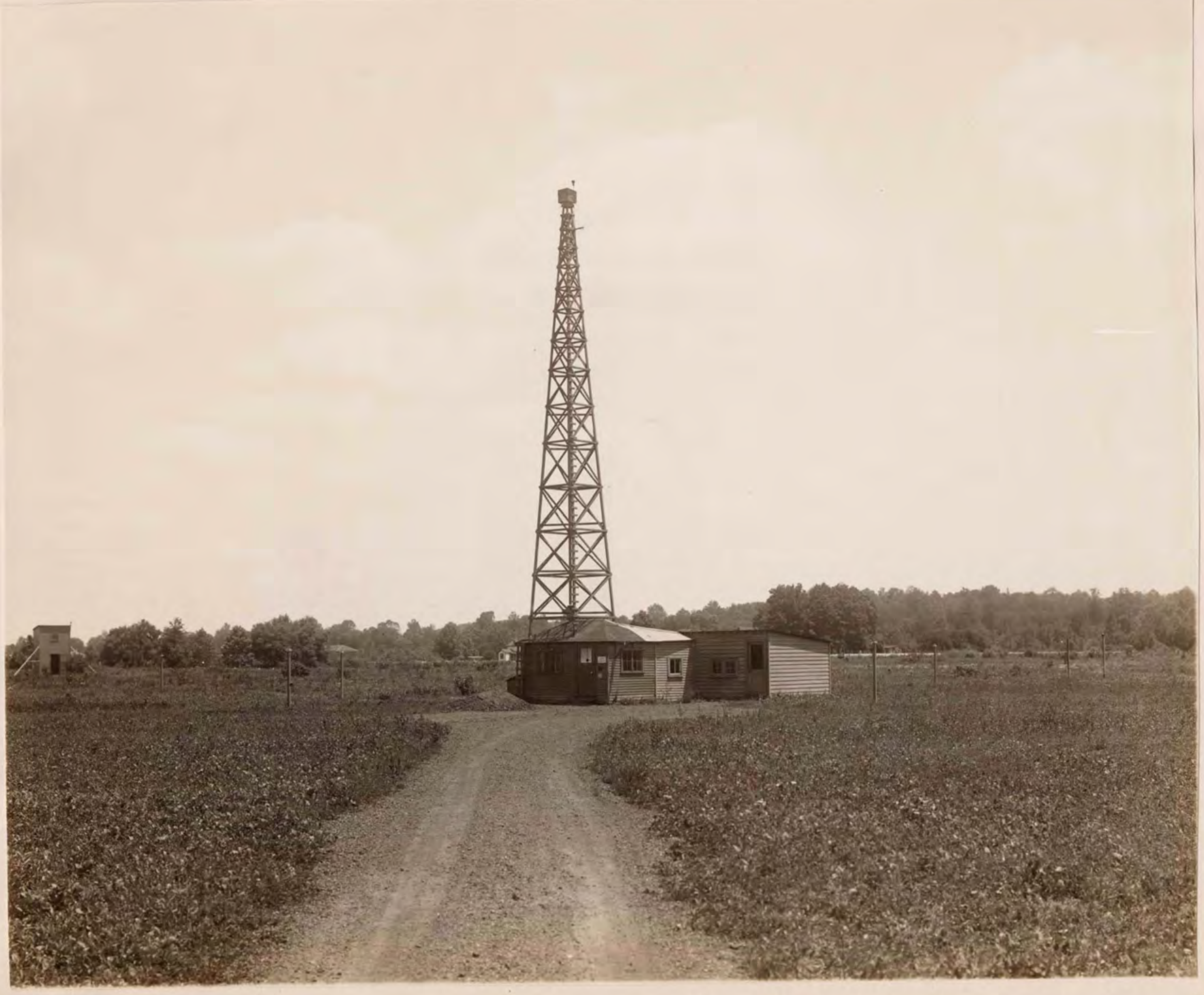


Fig. 6. College Park Station

IMPROVED AURAL RECEPTION

The goniometer as used by the Army, and based on the Bellini-Tosi patent was simply a mutual inductance device, each of whose two primaries conjoined with the two crossed secondaries and two crossed antennae to set up a phantom antenna, electrically equivalent to a loop antenna. By changing the relative positions of the primary and secondary coils, the plane of the phantom antenna was rotated through space. The primaries were of one or two turns connected in a tuned circuit fed by the output of the transmitter. A cam-operated relay was used to throw the power from one primary to the other, such that the signals as heard in the equi-signal zone interlocked, making one continuous sound. This meant that the circuit was broken on the radio frequency currents, which was highly undesirable.

The equipment which was brought out in the initial work at College Park was an improvement over this Army apparatus. The antennae were crossed at 90 degrees and each was fed by a 1 kilowatt power amplifier. The goniometer was placed in the circuit between the antennae and the amplifiers, which were supplied by a 250 watt master oscillator. The primaries were of 32 turns of insulated wire and the secondaries each of 8 turns of heavy litz wire. The interlocking was all done on the low-power side to obviate the necessity of breaking the R.F. currents as in the Army system. Tone modulation was accomplished by exciting the transmitting tube plates from a 500 cycle source.

Cam-operated relays excited the amplifier tubes with the Morse "N" (-.) and "A" (.-), such that the dot of the "A" came

between the dash and dot of the "N" and vice versa. Hence a single signal would be heard in the equisignal zone. This made it much easier to determine whether the signals were truly equal in intensity.

The apparatus operated satisfactorily in flight tests made over a one year period. However, the aural system of reception, improved to no matter what degree, has certain inherent weaknesses. The pilot not only has to listen for the radio range signals, but also for the weather and other important information being continually broadcast to him. In addition he has the actual operation of the plane to distract him from his radio duties. Moreover, the purely human element involved in the proper interpretation of the signals coupled with the distortion by various kinds of disturbances renders accurate guidance extremely difficult. Consequently the Bureau cast about for some better reception medium.

EARLY DOUBLE-MODULATION SYSTEM

The answer was at hand in the form of a method of visual reception conceived by F. W. Dunmore of the Bureau in June 1926, and described by him in Confidential Bureau Laboratory Report R-526-12aa. Although Mr. Dunmore did not at the time know it, the system was patterned after one which had been granted an early German patent. The idea was original with him, however.

Both antennae were to be supplied with R.F. power at the same time, modulated by different audio-frequencies. The fundamental transmitting circuit as already described was utilized, with a master oscillator supplying power to two amplifiers which feed the antennae through a goniometer. This differs from the self-rectifying method of exciting the amplifier-tube plates as already in use, in that the amplifiers were excited from a 500 and a 700 cycle source respectively. The receiving set circuit was so designed as to separate the modulation frequencies by use of selector and rejector circuits as shown in Fig. 7. The outputs of the 500 and 700 cycle transformers were rectified and made to buck each other through a zero-center micro-ammeter. It can readily be seen that the ammeter reading would be zero when on the course, while the needle would vary to the right or left depending on which side the plane was off course.

A modification of this basic system was also tried with some degree of success, but neither the one nor the other answered the basic requirement of simplicity and ruggedness. Moreover, were the whole transmitting or receiving system dead, the micro-ammeter reading would still be zero while the pilot might be far from his

course. While the fundamental plan of the double modulation beacon was sound, it required further research.

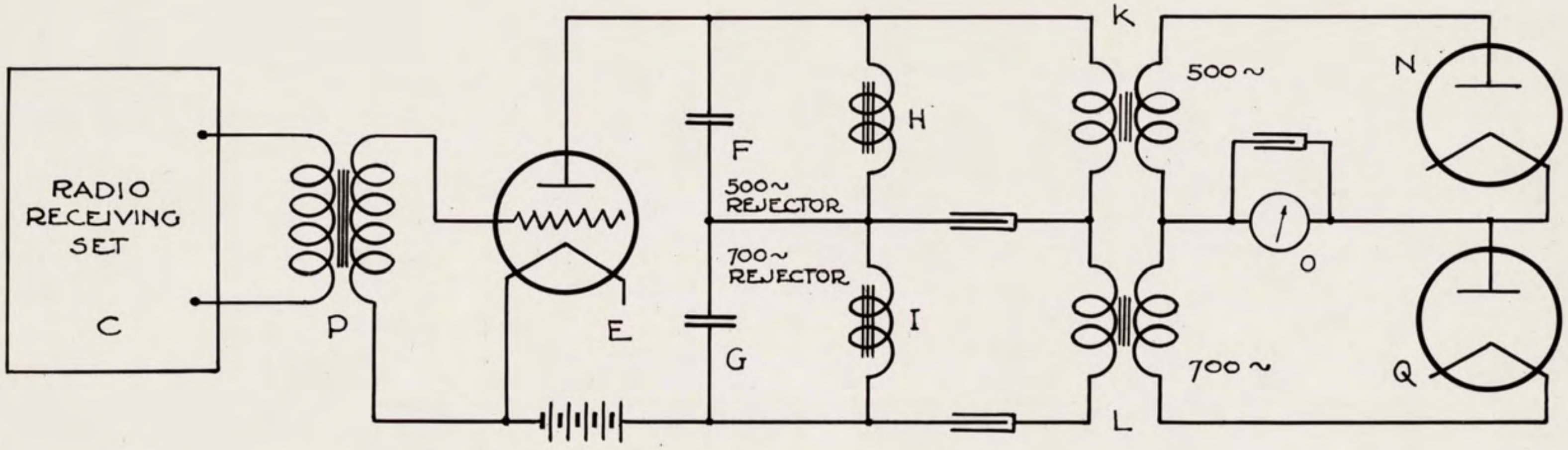


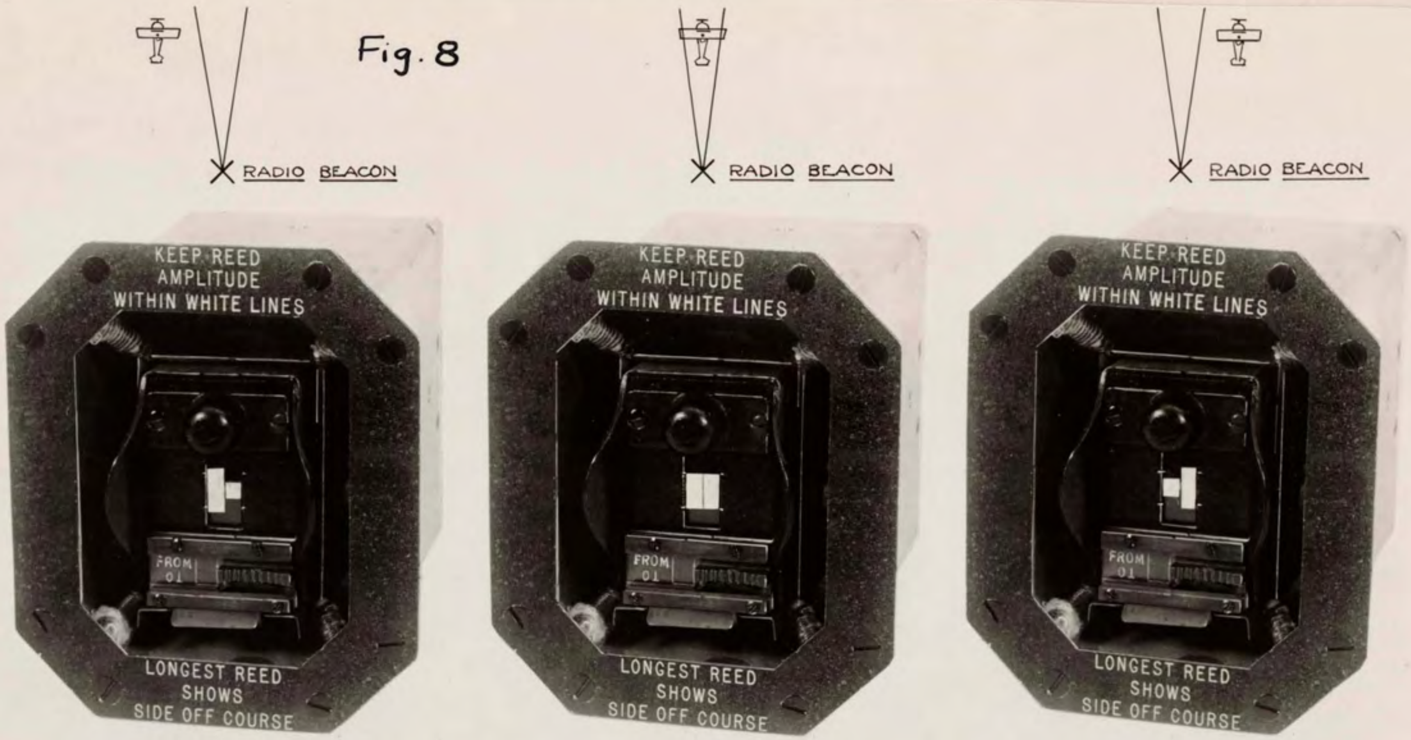
Fig. 7
Early Double-Modulation
System

THE TUNED-REED COURSE INDICATOR

By this time work at the College Park station had been in progress for almost two years, and it was in 1928 that Dunmore, in collaboration with H. Pratt, R. R. Gessford, and D. O. Lybrand developed the now famous reed-indicator. While details as to the developmental steps involved in its perfection are amply available, it will be quite impossible to do more than touch upon these since a thesis might be written on this piece of equipment alone.

With the same general transmitting circuit as formerly used, low frequencies were employed in the excitation of the power amplifier plates. The receiving circuit output feeds two electro-magnets which in turn operate two reeds placed in their field tuned to the modulation frequencies. The reeds vibrate in a manner similar to that employed in the frequency meters commonly met with in electrical laboratories. The reed tips are white against a black background for easy visibility. (See Fig. 8). When the plane is on course the reeds vibrate equally and appear simply as two equal white lines against the dark background. To prevent confusion to the pilot, the reed in the direction in which he is off course lengthens, while the other shortens in length. The unit is enclosed in a shock-proof mounting and placed in a prominent position on the instrument board of the plane, so that an occasional glance at the indicator suffices to keep the plane on the course. This is in contrast to the old aural system which involved the continual strain and tension of listening for signals whose distortion by interference might lead to further difficulty. A further advantage

Fig. 8



UNEQUAL REED AMPLITUDES
AIRPLANE OFF COURSE TO LEFT
(a)

EQUAL REED AMPLITUDES
AIRPLANE ON COURSE
(b)

UNEQUAL REED AMPLITUDES
AIRPLANE OFF COURSE TO RIGHT
(c)

is that the sharp tuning of the reeds cuts down interference to a minimum. As an illustration of the ruggedness of the unit it may be said that in several airplane crashes it has been the one instrument on the board to come through unscathed.

An ingenious plug-in arrangement was devised so that the reversal of side of greater deflection resulting from flying to or from the beacon, might be corrected. As now used, a simple operation keeps the unit constantly set so that the side of greater deflection is the side off-course.

In the initial radiobeacon for reed operation the modulation frequencies were obtained by the use of tuning-forks actuated by electron-tubes. The tuning-fork outputs were amplified before being used to modulate the 290 kilocycle current in the power amplifiers. It is very important that the modulation frequency be kept constant since the reeds are sharply tuned. In order that the equisignal zone remain fixed it was necessary that the root mean squared values of antenna current and the wave-forms thereof be the same in both loops. Moreover, the percent modulation had to be balanced in the two amplifier circuits. To prevent any coupling between the amplifier circuits it was necessary to use a great number of choke-coils and condensers. In order that all these requirements be met, the apparatus needed was too complicated for satisfaction.

It was realized that a circuit such as shown in Fig. 9 where the modulation is obtained from alternators, would eliminate the control apparatus formerly necessary. The difficulty in putting such a circuit into immediate operation was that constant speed

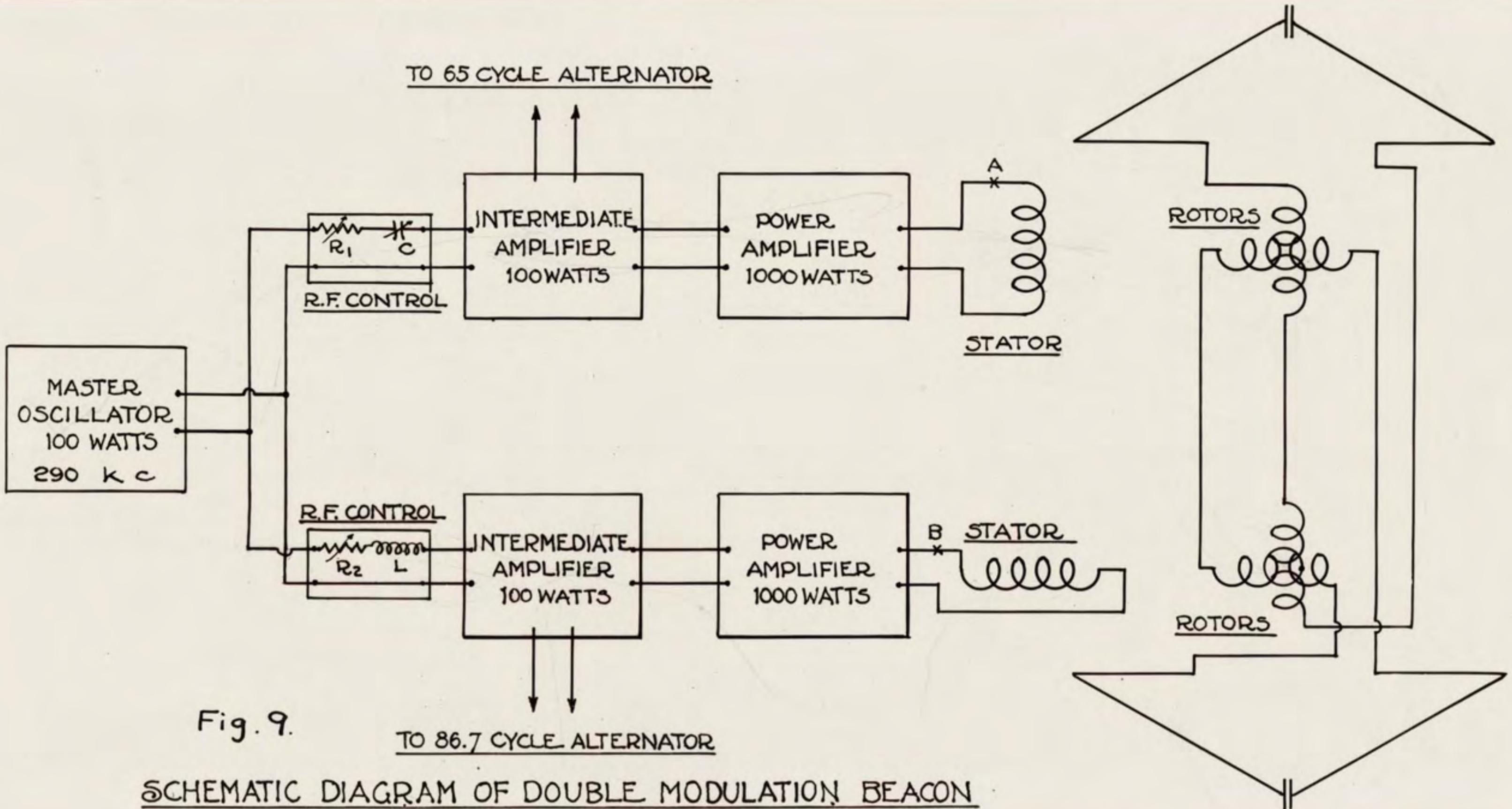


Fig. 9.

SCHEMATIC DIAGRAM OF DOUBLE MODULATION BEACON
FOUR COURSE TYPE

apparatus for driving the alternators was not available. Even the slight variations in frequency of the utilities' supply rendered the use of synchronous motors for the purpose impossible. The great advantage of simplicity to be derived from the arrangement led to further research in adaptation of alternators to modulation frequency supply. A very slight broadening of the resonant point of the reeds solved the problem. Also, by coupling the two alternators on the same shaft, the percent modulation changes equally in case of speed change.

As now used, the two modulation frequencies are 65 and 86.7 cycles. These are supplied by 6 and 8 pole alternators respectively. The speed must of course be 1300 revolutions per minute. The synchronous speed most nearly approaching to this value is 1800 revolutions. The reduction is accomplished by means of a chain drive to prevent slippage. This arrangement allows of 3/10 of one percent variation in the bus frequency. In the unlikely event that power can not be furnished within this tolerance, a motor must be used which will compensate for the change and maintain a more constant speed.

Such a motor was used satisfactorily at College Park in the operation of the experimental radio range. It was designed especially for the job by Leeds and Northrup. Part of the output of an inverted rotary converter is impressed across a frequency bridge. The bridge operates a galvanometer which in turn controls a motor-driven rheostat in the converter's shunt field. This control is maintained through relays. As soon as the frequency of the converter changes, the circuit operates to compensate the speed

in the right direction. In comparison with the complicated circuits necessary in the tuning-fork modulated system, this circuit is fairly simple.

AUTOMATIC VOLUME CONTROL

Now that the reed-indicator was an established fact, an incidental difficulty arose which required some research by W. S. Hinman, Jr., of the Bureau. It can readily be appreciated that, since the amplitude of reed deflection is dependent upon the power output of the receiving set, this amplitude is also a function of the distance from the radiobeacon source. The excessive vibration of the reeds, where close to the source, might cause damage to the unit were the volume not controlled in some manner.

The author is not competent to discuss the rather complicated radio circuits involved in the control system. The general scheme, however, is easily understood. Part of the output of the radio receiver is rectified by a copper-oxide rectifier (See Fig. 10). The resulting pulsating voltage is made as nearly as possible a direct voltage by the condensers and iron core inductor of the circuit. Application of this control voltage is made to the radio-frequency amplifier so as to decrease the sensitivity of the radio receiver. The control voltage varies directly with the receiver output. Hence, as the output voltage tends to increase, the control voltage also tends to increase in direct proportion thereto. This bucks down the increasing output and holds the receiver output constant for varying input pressure values. Since the output remains constant, the field strength of the electro-magnets operated thereby also remains the same for varying distances to the radio range beacon.

A meter measuring the radio-frequency plate current, and calibrated in miles, may be used to measure the distance of the plane from the signal source. This may be done because of the

variation of this current with voltage input, which in turn is a function of the distance.

When the distance becomes small, the input voltage rises and the plate current is low; the curve of voltage and plate current tends to become asymptotic to the voltage coordinate. A lower current meter provided with a relay-operated shunt for use at higher currents may be used. This becomes necessary because it is only at short distances, when the current is low, that the meter really has any practical value.

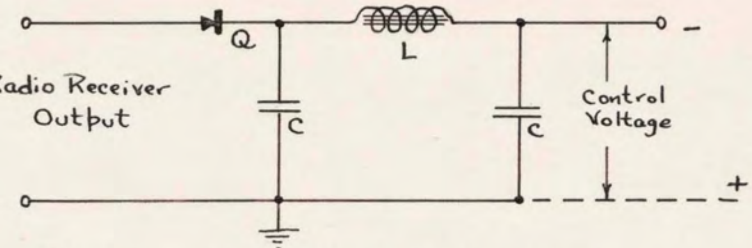


Fig. 10. Automatic Control Circuit

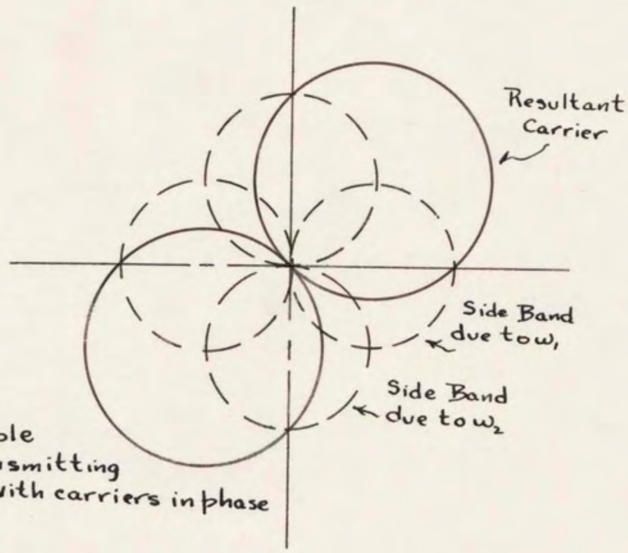


Fig. 11.
Combined double modulation transmitting characteristic, with carriers in phase

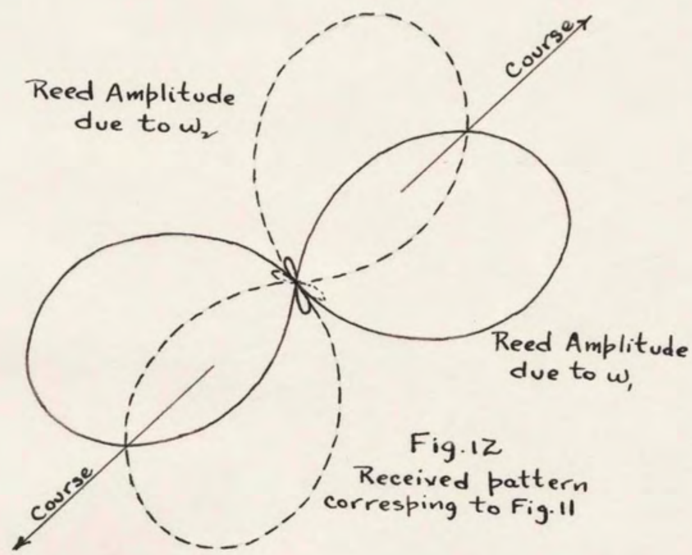


Fig. 12
Received pattern correspbing to Fig. 11

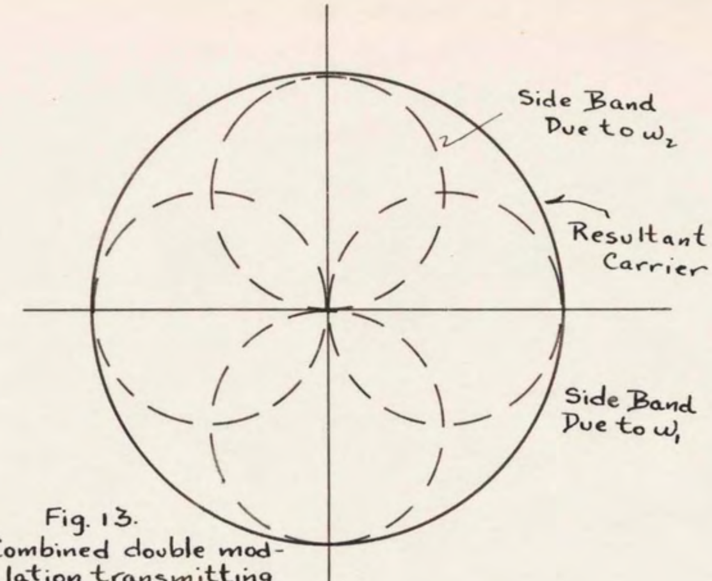


Fig. 13.
Combined double modulation transmitting characteristic with carriers 90° out of phase.

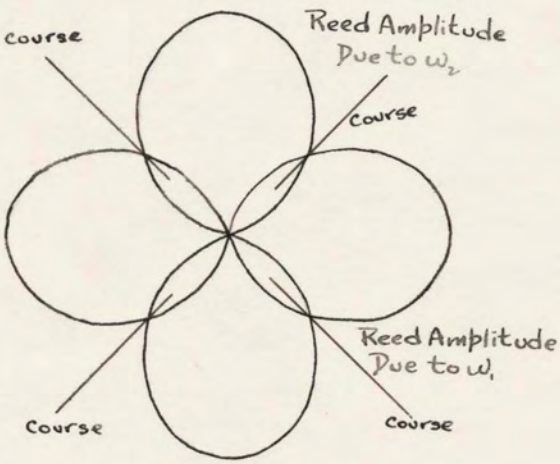


Fig. 14
Received pattern corresponding to Fig. 13.

BENT COURSES

The radio range as previously described made no provision for bending the courses intersecting at the beacon, to the already fixed airways. In order that the device be practical, it was necessary that this added flexibility be built into the system. The work to this end was done on the aural system by F. G. Kear and W. E. Jackson. Dr. Kear, now a lecturer in the Electrical Engineering Department at the University of Maryland, formerly was an assistant physicist at the Bureau of Standards. He was actively engaged at that time in the College Park experimental work. Jackson is a radio engineer with the U. S. Bureau of Lighthouses. These two men collaborated in a report on this subject, released in August of 1929. The following month saw an adaptation of the method to the double-modulation beacon by H. Diamond, a radio engineer with the Bureau of Standards. The principal experiments were carried on at College Park, but the actual installations were made at Bellefonte, Pa., and Hadley Field, N. J.

The radiation from each of the loop antennae is at 290 kilocycles; modulated in one case to 86.7 cycles, and in the other to 65 cycles. The radiation may in each case be broken up into the two components of a carrier frequency and two side-band frequencies. The carriers are in time phase and of the same frequency, and hence may be combined. The side-bands cannot. The maximum intensity of the combined carrier will be in the line bisecting the angle between the antennae, which is 90 degrees. The non-combining side-bands have their maximum intensity, of course, in the plane of the producing antennae. (See Fig. 11). The vibration of

the reeds of the receiving set is produced by the beating of the side-bands with the carrier, giving the reception pattern shown in Fig. 12. Hence there are only two courses produced, since the courses at 90 degrees thereto are negligible. In small airports it is conceivable that the two courses would be sufficient, but that these courses would have a 180 degree relationship is not likely. Hence, some variation must be made in order that the beacon be useable.

If one of the in-phase carrier-frequency currents be placed in time quadrature with the other, a revolving field may be created, (See Fig. 13), since the loops are in space quadrature. The reception pattern as set up may be seen in Fig. 14. Four courses are now obtained. By varying the current in one of the antennae, or by utilizing an auxiliary vertical antenna coupled to the amplifier output, these four courses may be set at arbitrary angles other than 90 degrees.

The system as just described theoretically, has been found in practice to give patterns corresponding quite closely to the theoretical. Several variations on this scheme have also been tried with success.

MARKER BEACONS

To serve to indicate dangerous or important locations on the beacon course, a marker beacon system was devised by the engineers at College Park. The marker beacon simply operates an auxiliary reed-indicator on the instrument board of the plane. The power of the beacon is low enough so that a signal can only be received within a 2 or 3 minute time interval, as the plane passes over.

Two basic systems were tried. One involved the use of an open antenna with a coded signal. The Department of Commerce airway beacon lights are coded to indicate their geographical position, and it was thought that a corresponding radio signal might be sent out on the marker beacon. In the use of the open antenna it is impossible to determine the exact beacon location unless the plane flies directly over it, but the coding device offsets to some extent this disadvantage.

The other basic system uses a loop antenna whose plane is in the course of the main radio beacon. Consequently a minimum, or theoretical zero zone exists at right angles to the main course at the beacon, because of the figure-of-eight transmitting characteristic. A coding arrangement is not practicable in this hook-up, but the location of a line perpendicular to the course at the beacon is accurately mapped out. Both systems have distinct advantages. The choice of system in a particular case would be governed by the conditions of that case.

The radio-frequency used at these beacons is the same as of the main beacon, modulated at 40 cycles. At the outset it was

decided to use 60 cycle modulation in order that the supply be obtained from the commercial 60 cycle mains, to cut down expense. The result was that a 5 cycle flutter appeared in the 65 cycle reed of the main indicator. This flutter was eliminated by changing to 40 cycles. The source is a 4 pole alternator driven by a 6 pole synchronous motor operating on the 60 cycle bus. The reed resonance curve is sufficiently broad so that minor frequency variations of the commercial system have no effect.

SIMULTANEOUS RADIOTELEPHONE AND VISUAL BEACON

In order that the airplane requirements of small space and light weight be met with, it became necessary to design receiving and sending equipment which would handle both beacon signals and radiotelephone messages simultaneously. It is imperative that the weather reports be uninterruptedly received no less than that the beacon signals be continuous. Moreover, a system had to be designed such that a great deal of equipment already in use might be utilized. The work was done on this adaptation by F. G. Kear and G. H. Wintermute at College Park, and reported on in May of 1931.

The apparatus as boiled down in the abstract of that report is about as follows:

A 2 kilowatt radiotelephone transmitter operates both into a non-directive antenna circuit, and also into two loop antennae through the proper amplifiers and a goniometer. The two systems are disposed symmetrically with respect to each other, and in so far as possible, coupling effects are balanced out. Proper phase relations are preserved by use of a phase-shift unit. A filter unit used on the receiving set keeps the various frequencies in their proper circuits.

Tests made with the equipment have shown it to be free from interference effects, and in all ways very satisfactory.

It is of incidental interest that the Bell Telephone Laboratories collaborated with Kear and Wintermute in this development.

REED INDICATOR OF POINTER TYPE

Mr. Dunmore made a further development in connection with his reed indicator, to overcome certain disadvantages observed in its operation. The new device used a zero-center meter as, it will be recalled, did one of the first double-modulation indicators described.

The oscillation of the reed is utilized to generate an alternating current. This is rectified and used to actuate a zero-center microammeter which gives the course indications. An extra set of pick-up coils is used to create a field for the generation of the electromotive force by the reeds. The two currents are made to pass through the meter with opposite polarities so that a zero indication means on-course.

It will be recalled that a disadvantage inherent in the early microammeter unit was that there was no indication in the event that the system went dead, the meter continuing in the on-course position. This bad feature is overcome in the reed converter by use of a signal-volume indicator in the output of the oxide rectifiers. It is a 0-500 microammeter connected so that it is deflected in the same direction by both currents. An indication of faulty equipment is thus given to the pilot.

The reed converter tunes more sharply and is more adaptable than the reed indicator. On the other hand, it is more apt to get out of adjustment; is heavier, bulkier and more expensive; and does not operate as well under conditions of interference. Both types are available at the present time, since they both have good points in excess of their bad ones.

MISCELLANEOUS DEVELOPMENTS

Under this heading come several of the important pieces of work, the detailed description of which would either involve repetition of material already presented, or discussion far beyond the limitations of time and space.

THE TWELVE COURSE, THREE REED INDICATOR

First is the design by Mr. Dunmore of a 12 course, 3 reed indicator making use ofthe principles already noted, and applicable to use at large airports. The device has the further advantage that by the use of 3 modulation frequencies it is possible to interpret the signals to give information to the pilot as to whether he is on or off course, and by how many degrees; also, if off, where the nearest course is, how to get on it, and which way he is flying on it.

NIGHT EFFECTS

The elimination of an annoying phenomenon known as "night effects" was accomplished quite late in the history of the station. The effects were noticeable chiefly at night and in cold weather, especially in mountainous terrain. Rapid and irregular variations of the indicated course, exceeding 10 degrees in some cases, constituted the difficulty. At any appreciable distance from the beacon the device was rendered absolutely ineffective. It was found that the night effects were caused entirely by antenna design, and could be eliminated by use of a so-called "transmission line antenna", consisting of 4 vertical antennae

on the corners of a square. The phenomenon was completely and effectively eradicated.

ENGINE SHIELDING

Considerable attention was given to the problem of properly shielding the ignition of the airplane engine, because of the sensitivity of the receiving set used. All parts of the ignition must be enclosed in metal of high conductivity. The wires are covered with metal tubes, and metal shields are used throughout. The equipment developed has been made commercially available.

STATION COURSE-SHIFT INDICATOR

To provide a means for checking the accuracy of the indicated courses at the beacon, a station course-shift indicator was brought out which is accurate to within 0.1 of one degree. The necessary adjustment of the transmitting system may be made when this instrument shows any variation from standard.

COURSE AND QUADRANT IDENTIFICATION

Lastly, a system was provided so that a pilot near a port need not be confused by the proximity of the converging courses. Before this development was made, a great deal of difficulty was experienced in orientation close to the beacon. The difficulty was remedied by the use of coded signals.

CONCLUSION

With the advent of the Roosevelt administration in 1933, all radiobeacon research was stopped. Orders to this effect were received on Inauguration Day, March 4, 1933. Since that time the College Park station has been dismantled, and the building is now used as the clubhouse for the Washington Air Derby Club.

The developments made, owing to interdepartmental bickerings, have largely fallen into disuse. The aural radio range is the one now in use, the last visual beacon having been discontinued the week of December 6, 1936. This is a most unfortunate situation, and it is to be hoped that the Department of Commerce will soon see fit to change its policy in this regard.

The author wishes to express his appreciation to the men of the Bureau of Standards for the consideration and cooperation shown him in the preparation of this paper. Photographs and literature were made amply available, and a real personal interest was shown.

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